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6. AUTHOR(S)
Prof. D. Pritchard

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Research Laboratory of Electronics
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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In the early part of the current grant period we made many improvements to the apparatus. We have used our now reliable separated beam atom interferometer to perform several pioneering measurements. Recent improvements in our fabrication techniques (at NNF) for 200nm period gratings with absolute phase stability over large areas, improvements in sensitivity and time response of our detector, and learning how to stretch thin foils extremely flat over 10 cm lengths have enabled us to operate our interferometer with a metal septum between the two separated components of the atom wave which interferes with itself at the third grating. By taking data in very short time intervals (two or three milliseconds) and improving the frequency response of our servo electronics, we have been able to overcome the effects of vibration, at least up to about 100 Hz, simply by storing the datum of each short period with other data taken at the same position (as measured with the laser interferometer). This has resulted in higher contrast for the fringes.

Our interferometer consists of three equally spaced transmission diffraction gratings which function as the beam splitter, mirrors, and beam combiner in a diamond shaped Mach-Zender interferometer. During operation, the 0^{th} and 1^{st} order beams from the first grating strike the middle grating (which is 140 μm wide) where they are diffracted in the 1^{st} and -1^{st} orders so that they converge at the third grating. At the second (middle) grating the beams have widths of 35 μm (FWHM) and are separated by 55 μm. The first two gratings form an interference pattern in the plane of the third grating, which acts as a mask to sample this pattern. This method of detection differs from most optical and neutron interferometers in that the interference is not detected in the far field. Our scheme requires only 2/3 the length of the usual far field detection method, giving us 3/2 greater separation of the beams in the interferometer for the fixed length of our beam tube.

An interaction region, consisting of a stretched metal foil positioned symmetrically between two side electrodes, was inserted in the interferometer so that the atom wave in the two sides of the interferometer passes on opposite sides of the foil. The foil was 10 cm long and 10 microns thick and the gap between the foil and each electrode, where the separated atom beams traveled, was 2mm. The shadow cast by the septum in the atom beam was typically 30 μ wide due to slight deviations of the stretched foil from perfect flatness. Because we have a conducting physical barrier between the separated beams, we can apply different, uniform, electric and magnetic fields to the portions of the atom wave on each side of the interferometer.

Due to the sensitivity of atom interferometers to inertial effects such as acceleration and rotation, all types of mechanical vibration are of serious concern in this experiment. The relative transverse position of the three gratings must be known to within a fraction of a grating period over the measurement time. This requirement is 25nm rms motion over several minutes for our "standard" interferometer configuration with 200nm period gratings. A similar requirement limits the motion of the gratings due to acceleration of the center of mass of the grating system during the time it takes the atoms to traverse the

interferometer, which is 1.3 ms. This means that the rms acceleration below ~ 900 Hz must be less than $10^{-2}\,ms^{-2}$. Finally, variations in the rotation rate throughout each ~ 20 sec fringe measurement time should be well below 10^{-4} rad/s.

We went to great lengths to passively isolate the machine from building noise, and took specific steps to reduce mechanical noise from the various mechanical vacuum pumps. Two levels of flexible coupling were added to the rough vacuum lines, the mechanical pumps were moved several meters from the experiment, and our turbo pump was isolated using a vacuum bellows. This helped a great deal but left us a factor of two away from our goal. A more compliant suspension for the apparatus was ruled out because the interferometer is too sensitive to low frequency rotational noise.

We completed our vibration isolation with the active position servo system. The three atom diffraction gratings are mounted on separate translation stages in the vacuum envelope. The servo's position sensor is an optical interferometer whose diffraction gratings are mounted on the same translation stages used for the atom gratings. By running the optical interference signal through a feedback network and applying the correction signal to a piezoelectric transducer on one of the translation stages, the relative motion of the atom gratings can be reduced to ~ 80nm rms. Mainly determined by low frequency < 100 Hz noise. By measuring the relative grating position every 2ms and later on correcting for the shifts, our effective vibrations have been reduced to 25nm rms. A switch of our detector wire from Pt-Ir to Re was motivated by the need to improve the response time to this value; it also turned out to be quieter, so detector noise no longer contributes significantly to the overall noise in the experiment.

Several other advantages were gained from using this optical interferometer to measure the grating position. This servo loop gives excellent stability over the time we take data, and even between adjacent data sets. Another advantage is that we can vary the reference voltage (and therefore the reference position) of the servo loop to scan a grating controllably over the interference pattern. This is how we have taken all of our data.

In addition to the required position stability in inertial space, the three gratings must be aligned so that their grating lines are parallel to ~ 10^{-4} radians. To achieve this, we developed a system of alignment that relies on laser diffraction from the support structure of the gratings (the grating bars are too closely spaced to diffract a HeNe laser beam). This method also has the benefit of aligning the gratings in the earth's gravitational field, important because of the interferometer's sensitivity to gravitationally induced phase shifts.

Improved data analysis allowed us to demonstrate an excellent signal to noise ratio in our interferometer. We made improvements in our original data analysis techniques in both software and hardware. The hardware we are using is a Macintosh Quadra 700 computer. The software consists of a set of macros and external subroutines used in a commercial data analysis package named Igor. The macros import the data, deconvolve the position from the lock loop error signal and provide the interface to our external subroutines that we have written in C. The external subroutines remove noise bursts from our data, bin the count data into positional bins, and extract the phase and amplitude of the interferometer signal. The peak to peak amplitude of our interference signal is

often 1600 Hz, which enables us to determine the interferometer phase to a precision of 3 milli-fringes in 1 min.

We have performed three pioneering experiments with our interferometer: a precise measurement of the polarizability of sodium, a magnetic rephasing experiment, and a measurement of the index of refraction of several gasses.

Our first measurement was a precise measurement of the polarizability of sodium.

We have observed the periodic rephasing of the independent interference patterns of the different Zeeman substates of the ground state as a differential magnetic field is applied to opposite sides of the septum. The real significance of this experiment is that one can determine the average velocity of the atoms that contribute to the interference pattern. Our current control of the direction of the ambient magnetic field in the apparatus is not sufficient for this purpose. We are working to improve this stray field.

We have recently begun an experiment to measure the "index of refraction" of a gas to atom waves which propagate through it, an experiment that gives information of a type not previously measurable. This experiment involves putting a gas on only one side of our septum. The interference pattern will display a phase shift as well as attenuation. The phase shift is due to refraction, and allows us to determine an "index of refraction" of the gas to atom waves (analogous to the light waves). This index is proportional to the real part of the forward scattering amplitude — information which is complementary to the imaginary part.

We have performed index of refraction measurements for all of the non radioactive rare gasses. Whereas the absorption is relatively similar for the different gasses, the index of refraction varies by more than an order of magnitude. It is therefore a much more sensitive probe of interatomic forces. Work is underway to understand this variation and its dependence on the long range interatomic forces, and also to extend the measurements to simple molecular gasses like N_2, CO, H_2O, and methane. This may serve to probe inelastic collision processes also.

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